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For

Apparatus and Method for Actuating Control Surfaces

by

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APPARATUS AND METHOD FOR ACTUATING CONTROL SURFACES

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention is directed to directional and attitudinal control for an airbore or sea-going vehicle and, in particular, an apparatus and method for actuating control surfaces of such vehicles.

2. DESCRIPTION OF THE RELATED ART

Airborne or water borne vehicles are often used to deliver a payload to a target location or to carry a payload over a desired area. For example, projectiles may be used in combat situations to deliver a payload, such as an explosive warhead or a kinetic energy penetrator to a target to disable or destroy the target. Surveillance vehicles may carry a payload designed to sense certain conditions surrounding the vehicle, such as objects on the ground or weather activity. Such vehicles typically include a plurality of control surfaces, such as fins, canards, flares, *etc.*, that are articulated to control the vehicle's direction and attitude.

In many conventional vehicles, a separate actuation apparatus (*e.g.*, a motor and a power transmission system) is provided for each of the control surfaces. For example, if a projectile includes four fins, four separate motor and power transmission assemblies would be provided. In such vehicles, one or more computers determine the desired orientation (*i.e.*, pitch, yaw, and roll) of the vehicle depending upon its destination, obstacles in its path, and other factors. The computer or computers then calculate the required orientation of the

control surfaces to attain the desired vehicle orientation and command each of the actuation apparatuses separately to orient the control surfaces accordingly.

It is generally desirable, however, for such vehicles to be lighter in weight, rather than heavier, so that their ranges may be extended while using an equivalent amount of propellant. Further, it is generally desirable for the contents of the vehicle other than the payload, *e.g.*, the motors, power transmission assemblies, and the like, to be more compact, so that larger payloads may be used within the body of the projectile. It is also often desirable to decrease the complexity of calculating the required orientation of the control surfaces to attain the desired vehicle orientation and commanding the actuation apparatuses to orient the control surfaces accordingly.

The present invention is directed to overcoming, or at least reducing, the effects of one or more of the problems set forth above.

SUMMARY OF THE INVENTION

In one aspect, the present invention provides an apparatus for actuating a control surface. The apparatus includes:

- a first spur gear;
- a first drive assembly engaged with the first spur gear;
- a second spur gear;
- a second drive assembly engaged with the second spur gear; and
- a gear assembly mechanically capable of being coupled with the control surface and engaged with the spur gears.

In another aspect of the present invention, a vehicle is provided. The vehicle includes:

- a control surface; and
- an apparatus for actuating the control surface, comprising:
  - a first spur gear;
  - a first drive assembly engaged with the first spur gear;
  - a second spur gear;
  - a second drive assembly engaged with the second spur gear; and
  - a gear assembly mechanically coupled with the control surface and engaged with the spur gears.

In yet another aspect, the present invention provides a method for actuating a control surface, comprising actuating the control surface in response to an actuation of at least one of a first spur gear and a second spur gear.

In another aspect, the present invention provides a method for actuating a control surface including mechanically combining two inputs into a single mechanical output to the control surface.

In yet another aspect, the present invention provides an apparatus for actuating a control surface including means for mechanically combining two inputs into a single mechanical output to the control surface.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like reference numerals identify like elements, and in which:

FIG. 1 is a front, perspective view of the an actuation apparatus according to the present invention;

FIG. 2 is a rear, perspective view of the actuation apparatus of **FIG. 1**;

FIG. 3 – **FIG. 4** are side, perspective views of the actuation apparatus of **FIG. 1** in which a housing has been removed to better illustrate the invention;

FIG. 5 is a cross-sectional view of the actuation apparatus of **FIG. 1** taken along line 5-5 of **FIG. 1**;

FIG. 6 is a cross sectional view of the actuation apparatus of **FIG. 1** taken along line 6-6 of **FIG. 1**;

FIG. 7 is an enlarged, perspective view of a portion of the actuation apparatus of **FIG. 1** in which some elements of the apparatus have been removed to better illustrate the invention; and

FIG. 8 is a stylized, side view of a vehicle incorporating the actuation apparatus of **FIG. 1**.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed,

but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developer's specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

The present invention relates to an apparatus and method for actuating control surfaces (*e.g.*, fins, canards, flaps, tabs, *etc.*) of an airborne or sea-going vehicle. In particular, the present invention provides an apparatus for actuating a number of control surfaces with a lesser number of drive motors. For example, one embodiment of the present invention comprises an apparatus for actuating four control surfaces with only three drive motors, corresponding to roll, pitch, and yaw. Alternatively, the apparatus may be adapted to control four control surfaces with only two drive motors, corresponding to, for example, pitch and yaw.

FIG. 1 – **FIG. 7** illustrate various views of an embodiment of a control surface actuation apparatus 100 according to the present invention. **FIG. 1** is a front, perspective

view of the actuation apparatus 100, while **FIG. 2** is a rear, perspective view of the actuation apparatus 100. **FIG. 3 – FIG. 4** are side, perspective views of the actuation apparatus 100 in which a housing 102 (shown in **FIG. 1 – FIG. 2**) has been removed to better illustrate the invention. **FIG. 5** is a cross-sectional view of the actuation apparatus 100 taken along line 5-5 of **FIG. 1.** **FIG. 6** is a cross sectional view of the actuation apparatus 100 taken along line 6-6 of **FIG. 1.** **FIG. 7** is an enlarged, perspective view of a portion of the actuation apparatus 100.

The actuation apparatus 100 includes a roll spur gear 104a (not shown in **FIG. 2**), a pitch spur gear 104b (not shown in **FIG. 1**) and a yaw spur gear 104c (also not shown in **FIG. 1**). The spur gears 104a – 104c are mounted to a central tube 106 by bearings 108a – 108c, respectively (shown best in **FIG. 5 – FIG. 6**), which allow the spur gears 104a – 104c to rotate with respect to the central tube 106.

Mounted to the housing 102 are a roll drive assembly 110a (best shown in **FIG. 4**), a pitch drive assembly 110b (best shown in **FIG. 3**) and a yaw drive assembly 110c (best shown in **FIG. 4**). In the illustrated embodiment, each of the drive assemblies 110a – 110c include a motor 112a – 112c, respectively, coupled with a speed reducer 114a – 114c, respectively. Each of the drive assemblies 110a – 110c includes a drive gear 116a – 116c, respectively, that is engaged with its corresponding spur gear 104a – 104c. For example, the drive gear 116a of the roll drive assembly 110a is engaged with the roll spur gear 104a and, when driven, the drive gear 116a rotates the roll spur gear 104a with respect to the central tube 106. Other configurations of the drive assemblies 110a – 110c, however, may be used to drive the spur gears 104a – 104c.

A plurality of thrust bars 118a – 118d (not shown in **FIG. 2**) is mounted to the central tube 106 by an inner thrust bar ring 120 and is mounted to the housing 102 by an outer thrust bar ring 122 (best shown in **FIG. 5**). Each of the thrust bars 118a – 118d supports one end of a gear assembly 124a – 124d, as will be more fully discussed later. The gear assemblies 124a – 124d are also supported by the housing 102 via bearings 126a – 126d (best shown in **FIG. 3 – FIG. 6**), respectively.

Each of the gear assemblies 124a – 124d is mechanically coupled with one of a plurality of output shafts 128a – 128d, respectively, which are, in turn, mechanically coupled, as will be described more fully below, with a corresponding plurality of control surfaces 804 (shown in **FIG. 8**) for actuating the control surfaces 804. Note that in the description that follows, the elements comprising the gear assemblies 124a – 124c, are identified by a suffix letter (*e.g.*, 128a, 132c, *etc.*) indicating to which gear assembly they belong. For example, an element of the gear assemblies 124a – 124d that is identified by the suffix "b" (*e.g.*, 128b) is an element of the gear assembly 124b.

Referring in particular to **FIG. 3 – FIG. 4**, each of the gear assemblies 124a – 124d comprises a roll gear 130a – 130d engaged with the roll spur gear 104a. The roll drive assembly 110a actuates the roll spur gear 104a and, in turn, the roll spur gear 104a actuates the roll gears 130a – 130d. Each of the gear assemblies 124a, 124c further comprises a pitch gear 132a, 132c engaged with the pitch spur gear 104b, such that the pitch drive assembly 110b actuates the pitch spur gear 104b that, in turn, actuates the pitch gears 132a, 132c. Each of the gear assemblies 124b, 124d further comprises a yaw gear 134b, 134d engaged with the

yaw spur gear 104c, such that the yaw drive assembly 110c actuates the yaw spur gear 104c that, in turn, actuates the yaw gears 134b, 134d. Thus, in the illustrated embodiment, all of the gear assemblies 124a – 124d are used to control the roll of the vehicle, while only the gear assemblies 124a, 124c are used to control the pitch of the vehicle and only the gear assemblies 124b, 124d are used to control the yaw of the vehicle. Alternatively, the gear assemblies 124a, 124c may used to control the yaw of the vehicle and the gear assemblies 124b, 124d may be used to control the pitch of the vehicle.

FIG. 5 provides a cross-sectional view of the actuation apparatus 100 taken along the 5-5 line in **FIG. 1**, illustrating one particular construction of the gear assemblies 124a, 124c, which are used in the illustrated embodiment to control roll and pitch. **FIG. 6** provides a cross-sectional view of the actuation apparatus 100 taken along the 6-6 line in **FIG. 1**, illustrating one particular construction of the gear assemblies 124b, 124c, which are used in the illustrated embodiment to control roll and yaw.

Referring to **FIG. 5 – FIG. 6**, each of the gear assemblies 124a – 124d includes a first screw 136a – 136d fixedly attached at one end to the trust bar 118a – 118d, respectively. In the illustrated embodiment, the first screws 136a – 136d are threadedly engaged with the thrust bars 118a – 118d. Second ends of the first screws 136a – 136d are received in bores 138a – 138d defined by second screws 140a – 140d. Each of the gear assemblies 124a – 124d also includes a thrust nut 142a – 142d threadedly engaged with the first screw 136a – 136d and fixedly attached to the roll gear 130a – 130d that meshes with, and is driven by, the roll spur gear 104a, as discussed above. Bearings 144a – 144d are disposed between the roll gears 130a – 130d and the second screws 140a – 140d and allows the roll gears 130a – 130d

and the second screws 140a – 140d to rotate with respect to one another, as will be more fully described later. The second screws 140a – 140d are supported by the housing 102 via the bearings 126a – 126d, such that the second screws 140a – 140d can rotate with respect to the housing 102.

Referring now to **FIG. 5**, the pitch gears 132a, 132c of the gear assemblies 124a, 124c are fixedly mounted to the second screws 140a, 140c. Translation nuts 146a, 146c engage the second screws 140a, 140c such that, as the second screws 140a, 140c are rotated by the pitch gears 132a, 132c, the translation nuts 146a, 146c translate along the second screws 140a, 140c.

As depicted in **FIG. 6**, the yaw gears 134b, 134d of the gear assemblies 124b, 124d are fixedly mounted to the second screws 140b, 140d. As in the gear assemblies 124a, 124c of **FIG. 5**, translation nuts 146b, 146d engage the second screws 140b, 140d such that, as the second screws 140b, 140d are rotated by the yaw gears 134b, 134d, the translation nuts 146b, 146d translate along the second screws 140b, 140d. In one embodiment, one or more of the second screws 140a – 140d are ball screws and a corresponding one or more of the translation nuts 146a – 146d are ball nuts.

As presented above, each of the gear assemblies 124a – 124d are mechanically coupled with a corresponding output shaft 128a – 128d. The output shafts 128a – 128d are attached to the control surfaces 804 (shown in **FIG. 8**). **FIG. 7** provides a perspective view of a portion of the actuation apparatus 100 with some elements removed for clarity in illustrating one particular mechanical coupling between the gear assembly 124d and the

output shaft 128d. While the mechanical coupling between the gear assembly 124d and the output shaft 128d is particularly illustrated in **FIG. 7**, mechanical couplings between each of the gear assemblies 124a – 124d and the corresponding output shafts 128a – 128d are effected in the same manner. Accordingly, while the following description addresses the mechanical coupling between the gear assembly 124d and the corresponding output shaft 128d, the description applies, in at least one embodiment, to the mechanical couplings between the gear assemblies 124a – 124c and the corresponding output shafts 128a – 128c.

In the illustrated embodiment, the translation nut 146d includes a clevis 148d that is coupled with a clevis 150d of the output shaft 128d by a linkage 152d and pins 154. In the illustrated example, as the yaw drive assembly 110c rotates the yaw spur gear 104c, the second screw 140d is rotated, which translates the translation nut 146d a distance along the length of the second screw 140d. The pins 154 and the linkage 152d transmit the translation of the translation nut 146d to the output shaft 128d, causing the output shaft 128d, and thus one of the control surfaces 804 (shown in **FIG. 8**), to rotate. Rotation of a pair of opposed control surfaces 804 effects a change in yaw of the vehicle.

To effect a change in roll of the vehicle, a pair of opposed control surfaces 804 are rotated in opposite directions with respect to a vehicle datum, while the other pair of opposed control surfaces 804 are rotated in opposite directions with respect to the vehicle datum. Thus, referring to **FIG. 5 – FIG. 6**, the thread direction of the first screws 136a, 136b and the thrust nuts 142a, 142b is opposite that of the first screws 136c, 136d and the thrust nuts 142c, 142d. In other words, if the first screws 136a, 136b and the thrust nuts 142a, 142b comprise

right-handed threads, the first screws 136c, 136d and the thrust nuts 142c, 142d comprise left-handed threads.

In a roll-changing maneuver, the roll drive assembly 110a rotates the roll spur gear 104a, which, in turn, rotates the thrust nut 142d. As shown in **FIG. 6**, the thrust nut 142d is mechanically coupled with an outer ring 156d of the bearing 144d. As the thrust nut 142 is rotated, it translates a distance along the length of the first screw 136d, which correspondingly translates the second screw 140d. However, the thrust nut 142d does not rotate the second screw 140d due to the bearing 144d disposed therebetween. The translation nut 146d translates a corresponding distance along with the second screw 140d. The pins 154 and the linkage 152d transmit the translation of the translation nut 146d and the second screw 140d to the output shaft 128d, causing the output shaft 128d, and thus the control surface 804, to rotate.

In the illustrated embodiment, the gear assemblies 124a – 124c operate in the same fashion as described above regarding the gear assembly 124d, except that the gear assemblies 124a, 124c include the pitch gears 132a, 132c, which are engaged with the pitch spur gear 104b, rather than the yaw gears 134b, 134d. Note that the roll gears 130a – 130d, the pitch gears 132a, 132c, and the yaw gears 134b, 134d are wider than their corresponding spur gears (*i.e.*, the spur gears 104a – 104c, respectively) to accommodate translation of the roll gears 130a – 130d, the pitch gears 132a, 132c, and the yaw gears 134b, 134d with respect to the spur gears 104a – 104c. For example, as the roll gears 130a, 130c are actuated by the roll spur gear 104a, the thrust nuts 142a, 142c translate the roll gears 130a, 130c with respect to the roll spur gear 104a and translate the pitch gears 132a, 132c with respect to the pitch spur

gear 104b. Accordingly, the roll gears 130a – 130d, the pitch gears 132a, 132c, and the yaw gears 134b, 134d have widths that accommodate such translations.

In some situations, it may be desirable to only control roll and pitch or roll and yaw. For example, in some embodiments of the present invention, the yaw spur gear 104c, the yaw drive assembly 110c, and the gear assemblies 124b, 124d may be omitted, such that only roll and pitch are controlled. In other embodiments, the pitch spur gear 104b, the pitch drive assembly 110b, and the gear assemblies 124a, 124c may be omitted, such that only roll and yaw are controlled. Thus, the scope of the present invention encompasses embodiments wherein only some of roll, pitch, and yaw are controlled.

Thus, the actuation apparatus 100 can be used to mechanically combine two inputs (*e.g.*, the desired changes in roll and pitch, or the desired changes in roll and yaw) into a single mechanical output to the control surface 804. The actuation apparatus 100 is, by way of example and illustration, but one means for mechanically combining two inputs (*e.g.*, the desired changes in roll and pitch, or the desired changes in roll and yaw) into a single mechanical output to the control surface 804.

It may be desirable in some situations, such as when initially assembling the actuation apparatus 100, to individually adjust one or more of the gear assemblies 124a – 124d such that the corresponding one or more control surfaces 800 are aligned or oriented in a particular manner. Such an adjustment may be accomplished by rotating one or more of the first screws 136a – 136d with respect to their corresponding thrust bars 118a – 118d. In the illustrated embodiment, ends of the first screws 136a – 136d each define a socket (proximate the 136a –

136d label lead line ends in **FIG. 1**), which can be engaged with a tool to rotate the first screws 136a – 136d with respect to their corresponding thrust bars 118a – 118d.

FIG. 8 depicts an illustrative application for the actuation apparatus 100, in which the actuation apparatus 100 forms part of a projectile 800. In this embodiment, the actuation apparatus is disposed within a body 802 of the vehicle 800 and the control surfaces 804 are attached to the output shafts 128a – 128d, respectively, of the actuation apparatus 100. In operation, the desired attitude (*i.e.*, the roll, pitch, and yaw) of the vehicle with respect to a datum is provided by, for example, a guidance or trajectory controller 806 within the body 802 of the projectile 800 to an actuation controller 158 (shown best in **FIG. 4**). The actuation controller 808, in turn, provides commands to the drive assemblies 110a – 110c to effect articulation of the control surfaces 804.

In the illustrated embodiment, the projectile 800 comprises a rocket motor 810 (shown in phantom) that includes a blast tube 812. Generally, blast tubes (*e.g.*, the blast tube 812) carry combustion products resulting from ignited propellant to the motor's nozzle (*e.g.*, a nozzle 814). While not required, some embodiments of the present invention may utilize the blast tube 812 as the central tube 106 (shown in **FIG. 1 – FIG. 6**).

This concludes the detailed description. The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular

embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.